2002

Research And Development Of Variable-Speed Scroll Compressor

H. Li
Beijing Polytechnic University

Q. Liao
Guangzhou Wanbao Compressor Company

R. Wang
Beijing Institute of Civil Engineering and Architecture

C24-4

RESEARCH AND DEVELOPMENT OF VARIABLE-SPEED SCROLL COMPRESSOR

* Li Hongqi, PhD, College of Environmental and Energy Engineering
Beijing Polytechnic University, No. 100, Pingleyuan, Chaoyang District, Beijing, P. R. China
Tel: 86-10-67391613, Fax: 86-10-67392741, Postcode: 100022
E-Mail: lihongqi@bjpu.edu.cn *Author for Correspondence

Liao Quanping, Guangzhou Wanbao Compressor Company
Qigan Town, Conghua, Guangzhou, P.R.China, Tel: 86-20-87861868, Fax: 86-20-87861808
E-Mail: gzscroll@wanbao-com.com.cn

Wang Ruixiang, Beijing Institute of Civil Engineering and Architecture
Zhuanlanguan Road, Beijing, P.R.China, Tel: 86-10-68322166; Fax; 86-10-68322166
E-mail: wang_ruixiang@hotmail.com

ABSTRACT

The adjustment and control mode of frequency conversion for an air-conditioner can make the refrigeration capacity adapt the variety of its load very well. Thus, it has many advantages such as low variety in in-door temperature, short time to reach the wished temperature, low energy consumption, low start electric current and low strike to electric source etc. This mode is widely used in room air-conditioners.

Up to now, household air-conditioners with frequency conversion control are very popular in China. This paper presented the research and the development of a variable-speed scroll compressor used in commercial air-conditioners with large input power. Different type of compressors were compared for this purpose, the results showed that scroll compressor is the most reasonable type to realize frequency conversion control. The electric control system was analyzed. Some engineering applications and technical requirements were also given in this paper for the reasonable, reliable and effective use of variable-speed scroll compressors.

NOMENCLATURE

f: frequency (Hz)
I: Electric current of compressor motor (Ampere)
K: Coefficient
Ne: Input power of compressor (Watt)
p: Number of motor poles
Qo: Refrigeration capacity (Watt)
RS: Rotating speed of compressor (Rev/min)
s: slip ratio
T: Torque (Nm)
Tc: Condensing temperature (℃)
Te: Evaporating temperature (℃)
Tr: Room temperature (℃)
V: Input electric voltage of motor (Volt)

INTRODUCTION

With the largest challenge of energy shortage in the following several decades, there is a very important task for the refrigeration and air-conditioning industries all over the world is to improve the performances of refrigeration system to reduce the energy consumption. Taking air-conditioners as example, more than 10 millions of air-conditioners were produced and sold in China. The production capacity is keeping increase and new manufacturers are also increasing year after year. A great amount of electric power is needed to support the operation of these air-conditioners.

The traditional air-conditioner with constant rotating speed is usually designed with its rated working conditions or its maximum thermal loads. It means that this kind of air-conditioner has a good performance only at its designing point. In fact, the working point at which an air-conditioner works is dependent on its real thermal load. But the thermal load usually varies with the variety of air temperature while an air-conditioner works. In

order to match the refrigeration capacity with the variety of thermal load, the air-conditioner must be turn on and off frequently according to the temperature in the adjusted room. This situation means that the air-conditioner often works at non-designed points. Its performance is decreased and energy consumption is increased. In the other hand, the frequent on/off of the air-conditioner will cause a large pulsation of room temperature and influence the comfortableness.

As mentioned above, one of the most important ways to improve the performance of an air-conditioner is to set up its ability to match the variety of thermal load. The best way to do so is to use a compressor with variable refrigeration capacity. Up to now, the air-conditioning compressors with variable rotating speed are popular in China. They brought a good benefit of energy. But they all belong to rotary compressors and the input power is limited to 3 HP below.

It is obvious that the higher the capacity is, the more the energy saving is. The main reason that the input power is limited is the lack of suitable compressors with high input powers. This paper introduces the development of the variable-speed scroll compressors

DEVELOPMENT OF VARIABLE SPEED SCROLL COMPRESSOR

Theoretically, there are two major ways to change the refrigeration capacity of such a compressor: to change its rotating speed or to change its displacement volume. That means variable speed compressor or variable volume compressor. The latter does not need to change the electrical control system of a traditional air-conditioner. But it will make the structure of the compressor become much more complex; and the manufacturing cost will increase greatly. A great amount of investment is also needed to re-construction the compressor production lines. This is very difficult for Chinese compressor manufacturers. For the variable speed compressor, though a new frequency conversion control system is needed, few structure changes and a little investment are needed. The most important thing is that compressor manufacturers and control system manufacturers could produce such compressors and control systems with existed production lines. This is the major reason that a variable speed compressor is selected.

Compared with traditional one, an air-conditioners with variable speed compressor has many advantages: it has low energy consumption and low start current; there is no strike to electrical source due to its low frequency start mode; it can operate with highest speed after start to reach the expected room temperature; it is able to change its speed in accordance with the variety of the thermal load to control the room temperature within a very small range. It can also avoid the frequent on/off operation (Fig. 1).

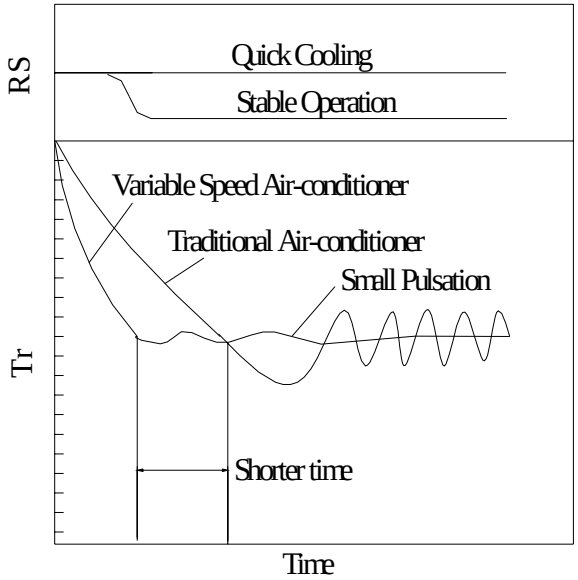

Figure 1: Comparison of variable capacity air-conditioner and traditional ones

There are two kinds of compressors that can be used in the variable frequency air-conditioners with large refrigeration capacity: reciprocating compressors and scroll compressors. For a reciprocating compressor, variable speed operation will cause a series of problems, such as noise and vibration, great pulsation of performance at different speed, oil lubrication and life of valve piece etc. After a detail feasibility analysis, it is obvious that reciprocating compressors are not suitable for the variable speed control. Considering that scroll compressors are gradually replacing reciprocating compressors in such air-conditioner market, a hermetic scroll compressor was finally selected.

The variable speed control of a hermetic compressor can be divided into two ways: AC frequency conversion and DC adjustment. The cost of latter is much more than that of former one in spite of the high performance of latter one, especially in large refrigeration capacity case. We just discuss the control mode of AC frequency conversion in this paper.

When a scroll compressor with AC frequency conversion control works, a frequency inverter supplies stator coil a three-phase AC current. A rotating magnetic field generated by this current generates an inducing current inside the rotor. The reaction between these two currents makes the motor of the compressor run. Its rotating speed can be calculated as below:

$$RS = 120 f (1 - s) / p \qquad (1)$$

It is obvious form (1) that the rotating speed is in direct proportion with frequency. The change of frequency directly causes the change of rotating speed. The variety of rotating speed means the change of compressor displacement. Thus the refrigeration capacity can be changed. For a two pole electric motor, its rotating speed will vary in the range of 1800～5400rev/min when its frequency varies from 30 Hz to 90 Hz.

In general, the load of a refrigeration compressor belongs to constant torque load. The output torque of the motor can be determined as:

$$T = K\left(V/f\right)2 \qquad (2)$$

This means that, for compressor motor and frequency conversion control system, V/f should be constant. Fig. 2 shows the PWM type control system.

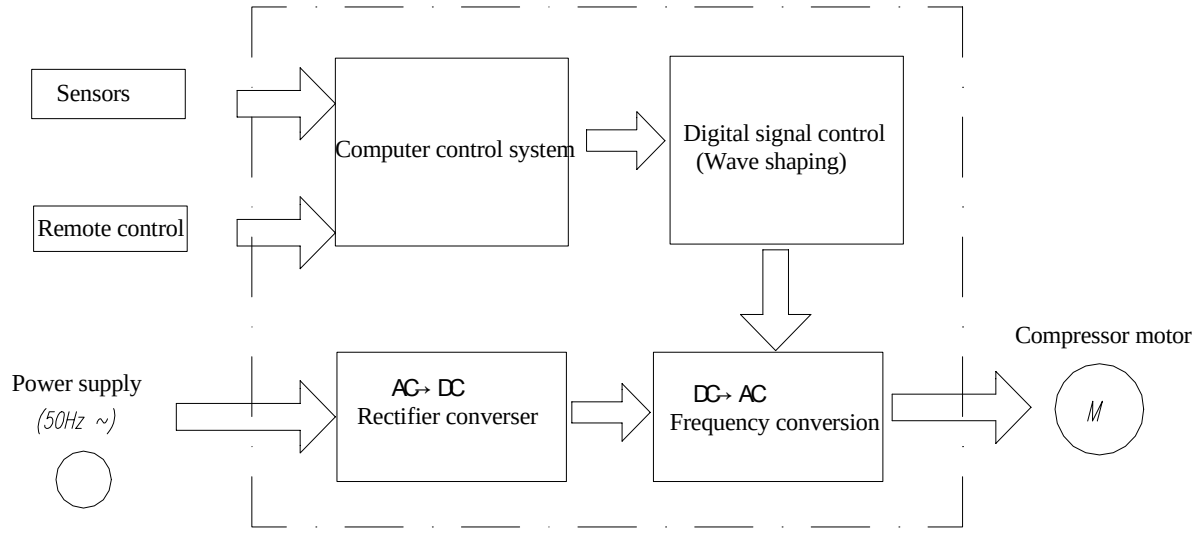

Figure 2: Frequency conversion control system

Based on the above work, the variable frequency motor was designed. And other necessary improvements in structure were also made; such as oil supply system, materials, backpressure chamber, strength, etc. A great many experiments were carried out on performance, noise, vibration, reliability and life, safety to check the design and manufacturing situation of this compressor. Fig. 3 shows the refrigeration capacity of the compressor at 120V, 50Hz of working condition. Fig. 4 shows the input power of the compressor at same working condition. Fig. 5 and Fig. 6 are the test results of noise and vibration respectively. Fig. 7 is the test results of coefficient of performance (COP) of this compressor.

The test results indicated that the developed variable speed scroll compressor could meet the need of the variable capacity air-conditioner.

APPLICATION AND ITS REQUIREMENTS

Application Cases

The variable speed scroll compressors can be used in many kinds of air-conditioning systems, such as one-to one room air-conditioner, VRA system, MDV system, parallel-compressor system, water cooling system etc.

Several application cases shown that there were many advantages for an air-conditioning system to use a variable speed scroll compressor:

- The overall energy consumption was greatly reduced by at lest 15%~30%.
- The temperature variety in the adjusted room could be controlled within ±0.5℃.
- The time to reach the expected room temperature was also greatly reduced by 30%.
- There was nearly no strike to electric source because of its zero Hz starting property.
- Its low cost makes it has great market potential in spite of the cost increase in control system manufacturing.

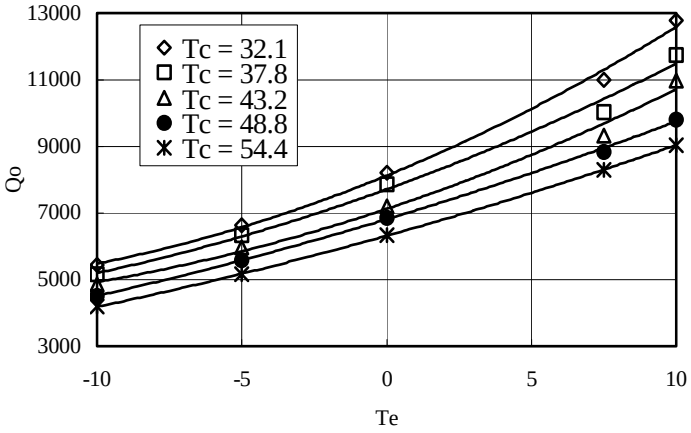

Figure 3: The refrigeration capacity of the compressor

- In case of a good match between air-conditioner capacity and room thermal load, the air-conditioner almost did not stop operating. This avoided the frequently on/off operation.

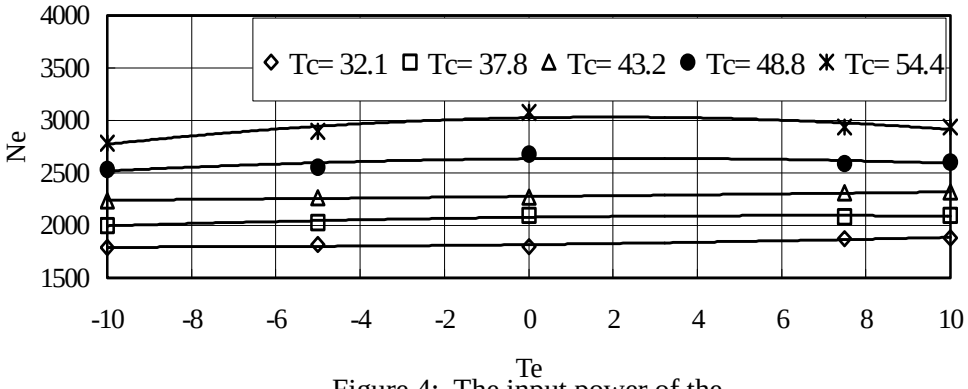

Figure 4: The input power of the

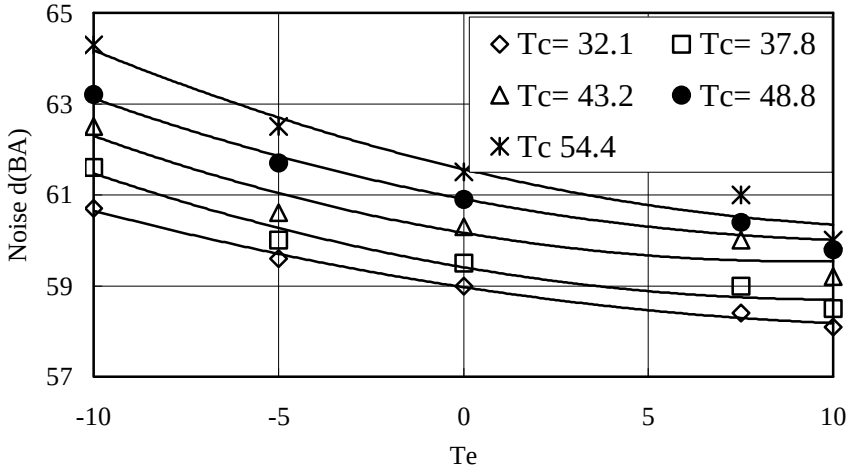

Figure 5: The test results of compressor noise

Fig. 8 shows a parallel-compressor air-conditioning system. Its out-door unit contains two compressors: a variable speed scroll compressor and a constant speed scroll compressor. Both of these two compressors can operate at any time. It means that this air-conditioner can work with both or any one of these two compressors. In this way, the refrigeration capacity of the air-conditioner can be adjusted in a certain range. The parallel-compressor mode also greatly expands the adjusting range of air-conditioning capacity.

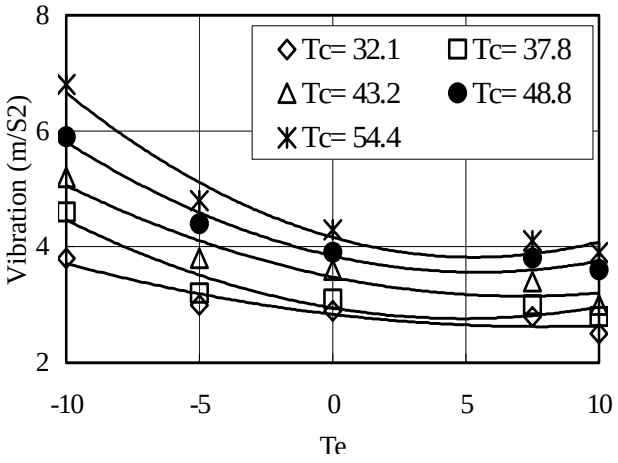

Figure 6: The test results of compressor vibration

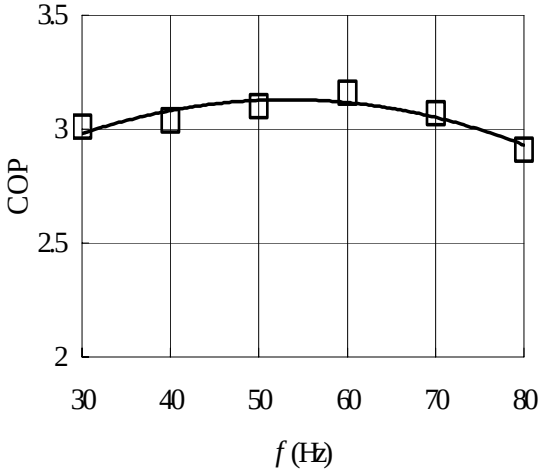

Figure 7: The test results of compressor

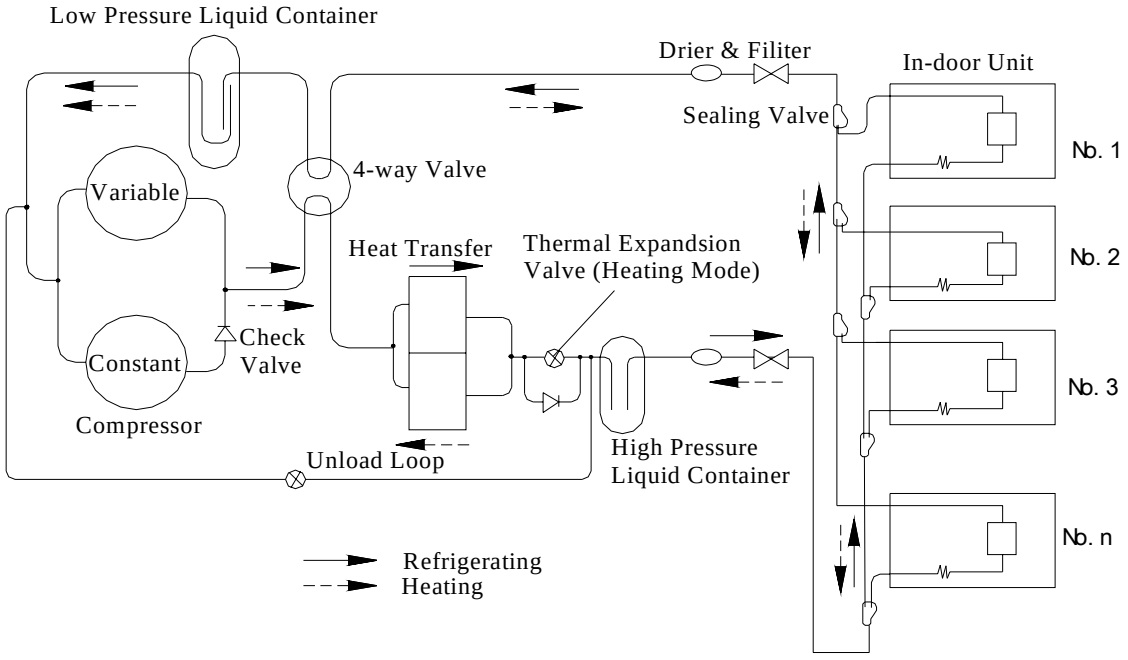

Figure 8: A parallel-compressor air-conditioning

Table 1 shows one of the control programs of this parallel-compressor air-conditioning system.

Application Requirements

To some extant, the effect of capacity adjustment for a variable air-conditioner is directly dependent on the correct use of variable speed compressor. This is also very important for the compressor life and reliability.

Table 1: One of the control programs of this parallel-compressor air-conditioning system

Refrigerating capacity (%)		30	40	50	60	70	80	90	100	110	120	130	140
Variable speed compressor	Frequency	30	40	50	60	70	30	40	50	60	70	80	90
		ON	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON
Constant speed compressor		OFF	OFF	OFF	OFF	OFF	ON	ON	ON	ON	ON	ON	ON

The operation and test experiences shown that there are many requirements that must be followed while application.

First of all, the V/*f* relationship of control system must be in keeping with that of the variable speed compressor. This is very important to keep the performance, the safe use and the life of the compressor. Figure 9 is a comparison of two kinds of control systems. One of them is suitable the variable speed compressor in V/*f* property; the other is not. Form this figure, it can be found out that the electric current of compressor motor only increases slightly with the increase of frequency when the V/*f* property of control is correct (the same as that of compressor). But for the un-suitable one, the electric current will greatly and quickly increases with the increase of frequency, much higher than the rated electric current of the compressor. This will result in the over-heating and over-loading of the motor, and greatly influence the safe use and the reliability of the compressor.

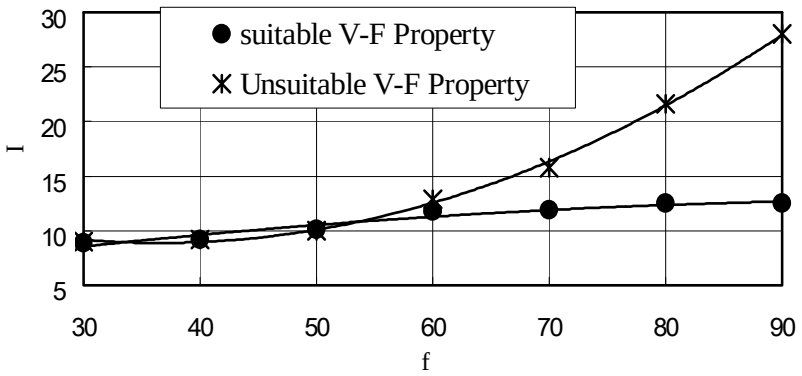

Figure 9: Comparison of two kinds of control systems

The other very important issue is that the system designers must pay great attention to the oil lubrication while compressor works. The continuous variety of compressor speed will change the oil discharge from the compressor and influence the oil flow back to compressor. Thus, there will be a danger that there is not enough oil inside the compressor. This will cause the compressor to be damaged. Especially for a parallel-compressor air-conditioning system, it is possible that the oil in one compressor transfers into other one while only one compressor works. In this case, an oil balancing tube or a back-oil distributor is suggested to be added to the system. The designers must also pay attention to the design of pipeline.

CONCLUSIONS

From all mentioned above, it is obvious that, as an effective method of energy saving, variable speed scroll compressors can be widely used in the engineering application of air-conditioners. Its advantages such as high efficient, low temperature pulsation and quick cooling or heating etc. will bring it a good market potential.

This paper only presents the preliminary research on the variable speed scroll compressors. The further research is under work now.